

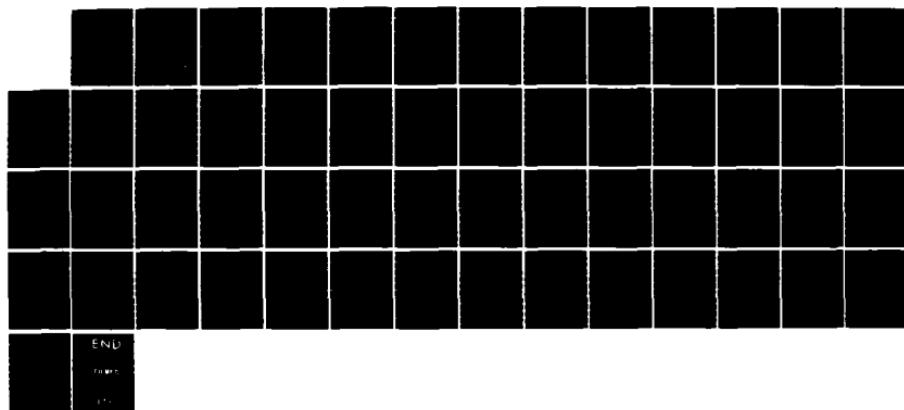
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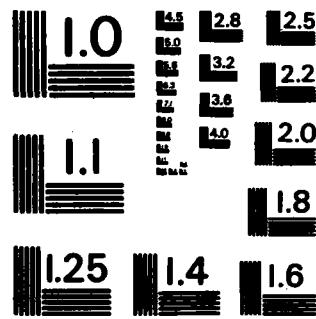
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LOUGHBOROUGH UNIV OF TECHNOLOGY (ENGLAND) DEPT OF CIVIL
ENGINEERING E G TRIMBLE ET AL. OCT 85 DAJR45-84-C-0024

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Expert systems in contract management.

A pilot study.

by E.G.Trimble

R.J.Allwood

F.C.Harris



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**Expert systems in contract management.
A pilot study**

by **E G Trimble
R J Allwood
F C Harris**

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**Note: The above title is the one used
in the contract. An alternative would
be "The potentials of expert systems
in Construction management".**

**University of Technology
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August 1985

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0. PREAMBLE

The objective of this study was to test the applicability of expert systems to Construction Management and to disseminate the findings. This report has been prepared in a form that should be suitable for circulation within the construction industry and thus secure the dissemination of findings.

Regarding the items in the statement of work the position is as follows

1. Selection of general purpose program. Extensive evaluation of commercially available programs has been undertaken and is reported in section 2. This evaluation prompted us to select SAVOIR as the program for a demonstration system.

2. Development of demonstration system. Discussion with senior representatives of the construction industry in the UK indicated that a system to select materials handling plant (cranes etc) for multi-storey construction would be a suitable domain. The development of this system is described in section 3.

The task of automatically loading an appropriate planning system proved un-demanding and its completion was reported in item 1.2 of our interim report dated December 1984.

3. Maintenance of contact with potential users. As reported in Section 3 we have established working arrangements with two contractors to obtain expert knowledge for incorporation in the system for materials handling.

4. Comments on other topics. We have also maintained contact with a broad spectrum of people within the construction industry, and extended this by working with the Construction Industry Computing Association. The views we have assembled on potential applications of expert systems are reported in section 4.

We have included an introduction (section 1) with the intention of explaining to potential users of expert systems the general philosophy of capturing hitherto uncodified knowledge. We have also included section 5 which offers recommendations regarding future work. In this draft final report we are keeping this preamble separate from the introduction and the later sections in the belief that, without the preamble, the report is in a format suitable for circulation as required by the technical objective.

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THE POTENTIALS OF EXPERT SYSTEMS IN CONSTRUCTION MANAGEMENT

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1.0 INTRODUCTION

The primary purpose of this report is to identify the ways in which expert systems can contribute to the management of construction. Section 4 itemizes and comments on the potential applications. The report is based on a study undertaken by the authors for the Construction Engineering Research Laboratory of the U.S. Army Corps of Engineers. In order to make informed judgements on the possible applications we undertook two important preliminary tasks, namely an evaluation of relevant computer programs and the compilation of a demonstration expert system. These tasks are described in sections 2 and 3.

Construction is managed with the aid of some formal techniques and a lot of intuitive feel. The latter is derived from the extensive experience of the managers. Amongst the formal techniques those which derive from Network Analysis (e.g. PERT, Critical path method etc) are the best known. These techniques provide a means of analysing any construction project and are based on a logical representation of the project in the form of a network of activities. The outputs from these techniques include

- o activity schedules, often in the form of bar charts
- o graphs of planned resource needs against time.
- o cost variance reports showing, against a set of cost codes, the value of work done and the cost of doing that work

When the outputs are suitably designed and appropriately selected they can provide valuable assistance to managers in their tasks of planning and control. If these techniques are to be successful the managers will have to make proper decisions on the following

- o choice of the particular technique and its supporting computer program(s)
- o choice of the appropriate levels of sophistication and detail
- o guidance in the marshalling of data from the real world, on activity sequencing, activity durations, required resources etc
- o decisions as to how often the project should be reviewed and re-analysed
- o selection of appropriate report formats and their circulation
- o explanations to the people who are to be involved with the system and the running of training courses

o monitoring of the effectiveness of the technique and its implementation and the adjustment of strategy when this seems appropriate.

We believe that, in practice, the informal expertise that the managers use is at least as important as the formal techniques. Until now this informal expertise has been recorded only in descriptive form. Conferences are held at which managers and their support staff exchange views on how the formal techniques can best be exploited and they describe their experience in different situations. The advent of Expert Systems provides a possible tool for capturing this kind of expertise in a form that can be readily conveyed to others. Thus it should be possible, for example, for the collective wisdom of the senior project managers in a company to be recorded in the form of an expert system which can provide guidance for the new recruits in the field of project management. Moreover, as further experience is gained the expert system will be modified to reflect the lessons learned.

The potentials are not in any way limited to project planning and control. We envisage for example that they could help in estimating, bidding, marketing, maintenance and a host of other domains within the construction industry. An extensive review of potential applications forms section 4 of this report.

Before continuing it should be noted that special computer programs have been written to assist in the development of expert systems. These programs are known as "shell programs" or "shells". In order to function they must be supplied with knowledge about a particular "domain". For example a commercially available program called SAVOIR could be provided with knowledge about a domain called "Planning and control of projects". This combination of program and knowledge would provide advice to a novice planner. The screen of the computer would present questions such as "Is the work repetitive or non-repetitive?", "State the approximate number of activities". Eventually he may be recommended to "Use resource oriented scheduling". Further refinements could provide advice on some or all of the managers' decisions listed above. For example it could advise on the sources of input data, on the format of output documents and on their circulation. It should also be noted that, when a user does not understand a question he can be supplied with detailed explanations. The form of the questions posed by the computer and of the advice it gives determine whether it will in fact be helpful to the novice planner. The over-worked expression "user friendly" is therefore a very important characteristic of the programs that are being developed in this field.

As indicated above we studied the potentials of expert systems in construction management in 1984 and 1985 using the following steps

An evaluation of available shell programs

The development of a demonstration application of an expert system relating to the choice of materials handling equipment (cranes etc) on multi-storey construction sites

A semi-structured review of potential applications and an assessment of them in the light of capabilities of the shell programs.

These steps are closely inter-related. For example the evaluation of shell programs helped in the selection of a shell for the demonstration application. The assembly of real-world knowledge and the reactions of managers highlighted the important characteristics of the shells and hence enhanced the practical basis for their evaluation. The evaluation of shells enabled us to appreciate in general what shells can do and what they cannot do. We took this information into account in our scrutiny of the potential applications.

These three steps are described in the following sections of this paper. An important by-product of our study is the realization that the process of acquiring realistic knowledge about a domain can be extremely challenging. We believe this topic has been under-researched to date and that its careful study in future will yield valuable dividends.

The study has been conducted in Britain and its findings relate to this country. However in many respects the findings are independent of the country of implementation and we believe that they should have widespread application.

2.0 EVALUATION OF SHELL PROGRAMS

Concurrently with our project for CERL Dr. Allwood and others at the University of Loughborough were evaluating shell programs that are available in the U.K. The principal purpose of this evaluation was to provide guidance to British researchers working on the subject of expert systems in construction. In association with that evaluation we determined the characteristics of the programs that would affect their relevance to construction management applications in general. We also ascertained which programs have facilities appropriate to the generation of a system to select appropriate construction plant (see section 3).

The shells we evaluated are listed in table 1. It will be noted that all these shells except ENVISAGE run on small computers. We considered this to be important as we believe that construction industry applications are much more likely to develop if the user has only to obtain software, or at most software plus an inexpensive machine.

The shells have general features in common, e.g. each provides facilities to draw inferences from a knowledge base (i.e. a set of information about a domain) in conjunction with a user's response to questions generated by the system. However, each shell is unique in the way these facilities function. Appendix 1 defines the terms that were used in our evaluation of the shells and will be a helpful reference in the interpretation of the remainder of this section.

2.1 THE EVALUATION STUDY

The number of expert system shells in existence is increasing very rapidly. Whereas formerly expert systems were mainly produced by research groups at academic institutions, most of the new ones are being produced by commercial organisations. This study has evaluated nine commercially available shells. We have included systems costing from a few hundred pounds to a few thousand pounds and mainly those on business micro computers. We have not included any systems requiring expensive specialist equipment such as "AI workstations". All the systems evaluated run on fairly common place machines.

To become familiar with the facilities and potential of the shells, an expert system was developed with each of them. Using just one set of source knowledge for all the systems would have helped in making comparisons between them, but might have meant using some systems inappropriately. Using different knowledge for each system might have enabled each to be shown to its best advantage, but would have made comparisons difficult. The compromise solution adopted was to use two "benchmark" sets of knowledge, one involving uncertainty and one not. The expert systems developed using the same knowledge bases were not forced to be identical. The basic sense of the knowledge was maintained, but facilities which make some things particularly easy in a system have been investigated and used. It was hoped that each system's potential would show through if a flexible approach was maintained in this way.

SHELL	PRICE (ex VAT)	COMPUTERS	DEVELOPER
X1	£495	IBM PC	Expertech Ltd., 172, Bath Road, Slough.
ESP ADVISOR	£600- £4000	IBM PC Apricot Sirius VAX	Expert Systems Int. 9, West Way, Oxford.
APES and Micro-prolog	£575	IBM PC Apricot MSDOS and CPM86 micros	Logic Based Systems Ltd. 40, Beaumont Ave. Richmond, Surrey.
TESS	£650	IBM PC	Helix Expert Systems Ltd. 11 Ludgate Circus, London, EC4M 7LQ
SAVOIR	£30000- £100000	IBM PC Apricot Sirius PRIME, VAX	ISI Ltd., 11, Oakdene Road, Redhill, Surrey.
EX-TRAN 7	£1995- £18000	IBM PC-XT-AT Sun GRID Compass VAX (UNIX)	Intelligent Terminals Ltd. 30, Hanover St., Glasgow.
KES	£4000- £24000	IBM PC-XT VAX	Software Architecture, & Engineering Inc., 16, New Park Road, Chichester, West Sussex.
ENVISAGE	£12000	VAX(VMS) ICL 2900	Systems Designers Plc., Pembroke House
SAGE	£2500	IBM PC VAX	Pembroke Broadway, Camberley, Surrey. (also from ICL)

TABLE 1 BASIC DETAILS OF SHELLS EVALUATED

The two "benchmark" knowledge bases were devised with a basic split of certain versus uncertain reasoning in mind. Benchmark number 1 is a set of regulations taken from The Department of Transport Technical Memorandum H9/73. These regulations have a crisply defined set of rules and conditions for selecting suitable safety barriers for highways in the United Kingdom. Benchmark number 2 is a set of rules divined from a text book, "The Movement and Distribution of Concrete" by J.R.Illingworth. This book gives advice on choosing suitable plant for transporting concrete on construction sites. This is a complex subject with few absolute conditions and conclusions.

The shells which did not include uncertain reasoning, evaluated using benchmark number 1, were ESP/ADVISOR, and APES. The shells which included uncertain reasoning, evaluated using benchmark number 2, were SAVOIR, KES, and ENVISAGE. The exception to this method of evaluation was EX-TRAN 7 which is different from the other shells in that it can induce rules automatically from sets of examples. It therefore seemed inappropriate to test the system using knowledge that already existed in a well defined rule format. Instead the cases taken from Illingworth were used to generate the rules.

Two other shells were studied in less detail, TESS and Expertech XI. There was not enough time to do a full evaluation of these systems, but since they are likely to generate some interest, it is useful to include some information on them. The notes and comments on these two systems were produced by looking at their manuals, and some standard demonstrations and knowledge bases provided by the manufacturers.

There are of course other shells than those we have examined particularly in the US. We give below brief notes on three we have some experience of.

The Loughborough Starter Pack is a simple Production Rule system ideal for a first introduction to expert systems. It is available for use on the IBM and Victor 9000/Sirius micros for £100 from Prof. E.G. Trimble, Department of Civil Engineering, Loughborough University of Technology.

At the other end of the scale systems such as LOOPS on the Xerox 1108 super-micro or Quintus Prolog on the Sun workstation provide general purpose AI programming environments of great power.

In the US there are other AI development systems available and we have been fortunate to have Prof. Ray Levitt of the Department of Civil Engineering, Stanford University help us by mounting part of benchmark No. 1 on the KEE system. This is his report on that work.

"The data about the roads to be investigated are stored in a series of frames. Each frame has a series of attributes such as MILE-POST NUMBER, VERGE-HEIGHT, HAZARD AT BASE OF VERGE etc. All of the data about the road section and its verges and central reserves are then stored in this frame "database". We then use rules similar to those which you would develop in any of the microcomputer languages (except that we can use variable names) to conduct a search through some or all of the road sections to

be evaluated. The rules have the general form "If road-section is in class 'road-sections', and if verge-height greater than three meters or if condition-at-base-of-verge is unusual-hazard, etc., etc. The structure of the rules then is quite similar to those used by MICRO-EXPERT or any of the other programs.

The KEE system will analyze the road sections in its frame-oriented "database" and print out a list of conclusions for the types of barriers required at the verge and central reserve side of each of the road sections in its database.

As you would imagine, the speed of execution on the very powerful LISP workstations is almost instantaneous. There is no perceptible wait-time between firing the rules and seeing the first conclusions emerge.

A major advantage of the KEE system is that it is possible to generate a rule-graph which is a graphical representation of a rule back-chaining to attempt to evaluate the truth of some of its premises when testing for different types of barrier applicability.

It is possible to operate this rule-graph in a "stepper" mode in which you hit the space bar to make the rule system check one premise at a time. In this way the structure and functioning of the rule system is made perfectly apparent and can easily be debugged.

The KEE system will shortly support automatic queries and modification of a wide range of commercially available databases so that the information will not have to be encoded in frames but rules can go to databases to determine the truth value of premises. In addition the KEE system supports simulation and now project management operations such as schedule analysis. All of this is provided in a very strong graphics environment which permits active images which show current slot values, and can be used with a "mouse" to modify current slot values, or to activate functions which live in the attribute slots of frames."

2.2 RESULTS OF THE STUDY

Our study revealed some general information namely

- o All systems represent knowledge by rules in some form; some systems also store facts.
- o Allowing for uncertainty in the knowledge base adds substantial problems of providing worthwhile statistical factors and interpreting the results of probability calculations.
- o A clearly developing feature appearing in the "second" generation shells is that of providing some overall control of the progress of the consultation. Usually, this is by a control section which functions partly in a procedural fashion, like a conventional program. It may allow a set of preliminary questions to be asked, branch to the most likely section of a knowledge base, terminate a line of enquiry when appropriate or insist on answers, other than "don't know", to critical questions before proceeding.

This control seems to us to be a very valuable feature in producing systems acceptable to users by limiting the number of questions asked.

- o Readers should be aware that the combination of uncertainty and control add substantially to the task of coding the knowledge base. To assist in dealing with this complexity some systems allow for the use of "demons". For example, in investigating ten goals, responses relating to goals 1 and 2 may prompt the line of questioning to change to goal 9. This could be achieved by coding called a "demon". In general demons are used to trigger special action when pre-defined conditions are met.

Our summarized comments on the shells we examined now follow. Our working papers contain substantially greater detail.

Xi is a deterministic production rule system with the knowledge stored in an English-like format and with the ability to use predicate logic if required. Only integer arithmetic is supported.

ESP/ADVISOR is a deterministic propositional logic system allowing numeric terms (integer and real) to be used in conditional tests. There are simple controls to access the structured knowledge, which is moderately comprehensible, and allows generous text to be output.

APES is Prolog augmented by routines to simplify setting questions to the user. It provides a friendlier sentence format than Prolog and supports integer and real arithmetic.

TESS is an inference network with only Bayesian rules. The knowledge, stored in a subject-verb-object predicate form, is not immediately comprehensible. The highly developed user interface with multi-windowed display and simple cursor control is very helpful.

SAVOIR is an inference network with Bayesian rules, fuzzy logic and extended Boolean logic which also handles conditional tests on real or integer variables. Control is provided by demons and external functions allow links to other programs. The knowledge base is not comprehensible until the system is well understood.

EX-TRAN 7 is a FORTRAN 77 based expert system kit containing a rule induction module and an inference engine employing a decision-tree knowledge representation. General purpose FORTRAN subroutines can also be included in the final expert system.

KES has three subsystems: production rules with certainty factors, an inference network with only Bayesian rules and a frame-based method called "hypothesize and test". Control is by a procedural type language. The inference network representation is not immediately comprehensible but the production rule version is.

ENVISAGE is an inference network with Bayesian rules and a fuzzy implementation of propositional logic. Sophisticated control is provided by demons and procedures and the terminal interface is well developed. The knowledge base is not immediately comprehensible but can be well structured.

SAGE is the forerunner of ENVISAGE with less control and less facilities for explanation.

2.3 SELECTION OF A SHELL

The choice of a shell on which to base the system for the selection of construction plant became an easy matter once we had assembled the foregoing information. We considered that the system must be capable of operating on a micro computer as we planned to take the system and its supporting computer to various respondent contractors during the assembly of the knowledge base. The shell must also be capable of dealing with an uncertain knowledge base and uncertain responses from the user. Reference to table 1 and to section 2.3 shows that the only systems that comply with these criteria are

TESS

SAVOIR

and KESS

Of these we favoured SAVOIR, initially on account of its availability on Sirius and Apricot computers. The Sirius is identical to the Victor 9000; the Apricot has all the facilities of the Sirius but is a small light-weight machine, ideal for taking to respondent companies even using public transport. Our choice of this shell was reinforced by its good control facilities which, increasingly, we see as important for systems based on real world data.

In May 1985 discussions at CERL revealed that Frank Kearney's staff had some reservations about SAVOIR. These were recorded in a note by Mike Young dated 28 May 1985. We have carefully examined his comments and conveyed our response to Frank Kearney in a note by Duncan Stewart dated July 1985. Our principal findings are that all but two of the reservations can be eliminated by revised coding of the knowledge base. The remaining reservations are

Ancillary programs written for the exit and re-entry facility must be compiled using PROSPERO PASCAL. This is a piece of software that is not readily available in the United States.

Although there is a good "help" facility that is activated at any stage by typing a question mark, this facility is not made apparent in introductory screen messages.

We have conveyed Mike Young's comments and Duncan Stewart's responses to ISI Ltd who market the SAVOIR shell.

Since this exchange of comment Dr. Allwood and Professor Trimble have had further experience of SAVOIR applied in a fairly complex real-world domain. This has, in their view, confirmed the suitability of SAVOIR for the domain described in the next section namely the selection of appropriate construction plant.

3.0 A SYSTEM TO SELECT CONSTRUCTION PLANT

To minimize duplication of effort use was made of the results of a parallel project which included the development of an expert system to provide advice on the selection of appropriate equipment (cranes etc) for handling materials on multi-storey construction work. For the purposes of the CERL project the work was monitored in regard to

- o The responses of the contractors' representatives
- o The level of difficulty in establishing the knowledge base
- o The contractors' views concerning the usefulness of expert systems for construction management generally.

As explained in section 2 the system is based on the shell program SAVOIR. The version of this system current in May 1985 was demonstrated to Mr. Frank Kearney and his colleagues during Professor Trimble's visit to CERL. It is now being further refined and it seems likely that new features will continue to be added for several years. At any convenient juncture we shall be happy to demonstrate it to representatives of the U.S. Army's European office. It was demonstrated on 6 August 1985 to Miss Sine Hill of CERL during her visit to Loughborough.

A full report on this work is being prepared and will be available by September 1985. The principal features of the work are now described.

We initially prepared a trial system using a shell called MICRO-EXPERT which is, in effect, an earlier mark of SAVOIR. The trial system was based on the personal knowledge of Dr. Frank Harris. It should be noted that both MICRO-EXPERT and SAVOIR provide for uncertainty. Thus to the question "Is the site free from unprotected excavations?" the user could respond in the range -5 to +5

-5 meaning "It certainly isn't"

0 meaning "I don't know"

+3 meaning "I'm fairly sure that the answer is yes"

+5 meaning "Certainly Yes"

We established contact with two large contractors namely Taylor Woodrow Ltd and Tarmac Ltd in order to obtain practical data by which to extend and develop the system. We found that in each company we needed two levels of access; a senior executive who authorised the work and a more junior person who had the necessary expertise at an appropriate level of detail.

Our original intention in approaching these companies was to describe our own system, invite comments from the experts, amend the rules in the system in the light of the comments and to proceed on an iterative basis by means of repeated visits. We decided against this approach, however, as we feared that it would prejudice the responses and thus introduce bias. Instead we adopted the approach of patient discussions with the experts until the necessary relationships between the variables emerged.

As initial segments of knowledge became available we coded these to provide initial demonstrations. The respondents were able to relate to these demonstrations and to provide further knowledge to build into the system. We understand that this approach is being used at CERL for knowledge acquisition and was used in developing PROSPECTOR. It should be recognised that, while the approach is good as a means of avoiding biased responses, it is consuming of time, patience and money. Where similar domains have already been coded it may be possible in future to use structured interviews for the areas of previously defined knowledge.

We realised that different contractors may well have different ideas about the factors that determine the selection of construction equipment. We were therefore prepared to develop one system for each contractor. We had plans to compare the systems once prepared and thus ascertain which sectors of the knowledge base (if any) were common and which unique to the particular contractor. It quickly became apparent however that the technical aspects of the model (i.e. engineering considerations) were common while financial constraints (e.g. the policy for calculating internal hire rates etc) were not. We therefore proceeded with the development of the technical features using responses from both Taylor Woodrow and Tarmac. Appendix 2 is a record of a dialogue session using the technical features incorporated up to the end of June 1985. It will be noted that the user is first asked questions about the soil and about unprotected excavations in order to establish whether a tower crane can be supported. He is then asked about the geometry of the building to be constructed to enable the required specification of a crane to be determined. There are further questions (not illustrated) that determine the appropriate ancillary plant such as trucks to bring materials within the range of the crane.

During the assembly of rules to date the following practical points have been noted.

Very often the planning engineer is currently using crude rules of thumb to guide his decisions. While these can be incorporated in an expert system there is then the danger that they will be applied, by the system, in inappropriate circumstances.

The figures to represent probability (the affirm and deny factors for Bayesian rules) cannot be assessed directly from discussion with a domain expert. It is necessary to postulate alternative sets of antecedents and obtain the expert's guess as to the probabilities of the outcome. The system compiler can then derive the factors.

The system developed so far does not take account of the continuity of usage of the resources e.g. the handling equipment, ancillary equipment, and labour. Careful refinements will be needed to deal with this aspect.

The system so far deals with buildings whose plan is regular in shape. Further adjustments will be needed to deal with buildings of irregular plan.

In the immediate future the following enhancements will be made

Developments to improve the consultation.

More extensive details of support plant e.g. fork lift trucks, conveyors etc.

Use of exit and re-entry facilities to provide access to a data base containing data on physical characteristics of plant items, their availability and cost.

In the longer term we plan to extend the system to deal with formwork strategy and its impact on the construction schedule and the utilization of resources. We plan also to provide for irregular shaped buildings.

We believe that the system as it stands can be useful as an aid to inexperienced planning engineers. With the enhancements envisaged it should be capable of achieving more economical selections of plant and thus be justified in commercial terms.

The contractors' senior representatives have expressed considerable interest in the exploitation of expert systems; one has provided input regarding our evaluation of their potentials (See section 4).

The work in assembling the demonstration system was valuable during the evaluation of shell programs in that the observed constraints in the real world provided guidance as to the facilities that are required and their relative importance. It was valuable also in our assessment of potential applications in that exposure to the constraints of assembling a realistic system provided guidance as to the kind of situations in which expert systems may be used.

4.0 REVIEW OF POTENTIAL APPLICATIONS

We approached this subject by first assembling, relatively uncritically, a list of topics in construction management which require the exercise of expertise. We then subjected each item to review in the light of what we now know about existing expert system shell programs. We also took account of the fact that some domains may not fit well within existing shell program but are capable of being represented by coding written specially for that domain. From the point of view of the user we see expert system software as falling into three categories, namely

- o Those which look at a set of pre-defined goals and assess which if any of the goals applies. For example a goal could be a piece of advice such as "You are recommended to use a tower crane". Alternatively it could be the result of diagnosis such as "The fault is in the transmission system". More than one goal may be found. For example a mobile crane (within defined criteria) may be just as suitable as a tower crane.
- o Those which deal with uncertainty. These look at a set of pre-defined goals and offer advice or diagnosis with some form of probability. For example, the advice to use the tower crane may be offered with a probability of 4.5 (on a scale of 0 to 5) but the mobile crane is recommended with a probability of 3.0. The system will then have to take other factors into account in arriving at his selection.
- o Those which synthesize a goal. For example, the recommendation may be to use a tower crane, with a height to underside of jib of 80 metres (260 feet), with a luffing jib, of radius 30 metres (98 feet) and a capacity of 2 tons. The components of this advice may be offered as one composite statement or as a series of separate pieces of advice during a continuous dialogue between the user and the computer.

In assembling the list of possible topics for review we worked with the Construction Industry Computing Association in preparing a report entitled "The future of expert systems in construction management" referred to later as the CICA/LUT report. This work is part of the study for CERL.

The remainder of this section is divided thus

- o Comments on the topics listed in section 3 and 4 of the CICA/LUT report.
- o Other applications not covered by that report.
- o Comments on the costs of application of expert system and their potential benefits.

4.1 COMMENTS ON EXISTING DEVELOPMENTS

These comments are intended to highlight the domains that have been selected for study. No comment is included on the work at CERL or Loughborough. The domains are now listed with comment.

Design of building services

Work is proceeding at the Building Services Research and Information Association and at the Polytechnic of the South Bank. The former is aimed at the initial decision stages while the latter is more broadly based.

Interpretation of regulations

Work is being done by the University of Sydney on sunlight requirements, by Birmingham Polytechnic on a British standard for measuring building work and by the Water Industry on regulations and codes of practice relating to water distribution management.

Estimating procedures and cost control

Work is proceeding at Salford University and Portsmouth Polytechnic. Funding at Portsmouth is very substantial and they are adopting a sophisticated approach.

Evaluating contractors safety practice

Selection of earth-moving plant

The decision to bid or not

These three domains are being developed successfully at Stamford University.

Claims analysis

This work is proceeding at the University of Colorado. It is well known to CERL and requires no further comment.

Building defects diagnosis

Work is proceeding at the Building Research Establishment on a system to diagnose the cause of damp penetration in buildings. Professor Trimble and Dr. Allwood have an involvement in this project and believe it will be valuable in releasing experienced experts for new work. We believe that a similar approach will be useful in the investigation of structural failures in buildings.

Buildability

Work is proceeding at the University of Reading.

Intelligent project management systems

It seems that the Digital Corporation has had some success in this domain with particular regard to the design and manufacture of computers. The PLANIT community club in Britain is developing a somewhat similar approach. It should not be assumed, however, that methods that are satisfactory for the control of high technology projects will also be satisfactory in Construction. Behavioural research at Loughborough has strongly supported the view that the need in Construction is for project systems that are simple enough to be operated directly by foremen and supervisors. It may be possible to develop a system that is more sophisticated in its calculations than traditional project systems but at the same time is easier to use. If this proves to be the case, this domain would certainly be worth pursuing.

4.2 COMMENTS ON POTENTIAL APPLICATIONS

Many of the potential applications that are listed will require considerable research of the domain before the relationships between the important variables can be satisfactorily established. It may emerge eventually that representation other than by expert system methods would be appropriate. Attempts to develop expert systems in these applications may nevertheless act as a stimulus in establishing a clearer understanding of underlying expertise. In some of the applications, notably those in which a possible structure for an expert system is apparent, a brief comment follows the description of the application.

The potential applications are listed under the following headings.

Pre-Construction Decisions

1. Alternative Contractual Arrangements
2. Assessment of the Client's Needs
3. Client Information, Monitoring and Control
4. Land/Building Economics

Marketing

1. Determining Sources of Work
2. Public Relations
3. Advertising, Promotion and Publicity
4. Analysis of Market Information
5. Market Forecasting
6. Product-Market Strategy

Estimating and Surveying

1. Bidding Strategy
2. Invitation to Tender
3. Management of Estimate and Tender Preparation
4. Cost Planning
5. Probabilistic Cost Estimating
6. Forms of Contract
7. Contractual Claims
8. Methods of Measurement
9. Cost Comparisons

Project Planning, Management and Control

1. Choice of Planning Method
2. Preparation of Construction Programmes
3. Representation of Network Analysis Knowledge
4. The Method Statement
5. Safety, Health and Welfare

Training

Resource Management

1. Technical/Managerial Staff
2. Contracts of Employment

Financial Management

1. Capital Investment
2. Taxation
3. Financing Methods
4. Sources of Finance
5. Insurance
6. Loan Applications
7. Arbitration
8. Interpretation of Accounts
9. Company Doctor

Pre-Construction Decisions

1. Alternative Contractual Arrangements

The client has a range of alternative contractual methods open to him when considering a project, such as:

Open/selective tendering
Serial and term contracts
Design build/develop and construct
Fee contracting
Management contracting
Two-stage tendering
British Property Federation

each of these methods having its own merits and drawbacks. An intelligent knowledge-based system could be prepared, setting out these comparisons to enable both the client and the contractor to make a decision on the most appropriate contractual arrangements for any particular project.

It could well be found that the method most suitable for the client is also the one most profitable to the contractor.

Comment.

Alternative methods form the goals of the system. It should be straight-forward to identify the goals. A demonstration system has been prepared at Loughborough.

2. Assessment of the Client's Needs

A system to assist in the preparation of the client's brief to the design team. By determining more accurately, at an early stage, the client's actual requirements, it would be possible to construct a project more efficiently and economically.

Comment.

Substantial research would be needed to ensure that the advice from the system is appropriate. A joint workshop arranged by the National Science Foundation and the (British) Science and Engineering Research Council (Stanford 1983) recommended that such research should be undertaken.

3. Client Information, Monitoring and Control

During the design and construction stages of a project, information needs to flow to and from the client. Much of the information is similar from project to project and, although a construction professional may well have dealt with such situations several times before, it may be the only time that a client does.

It would help communications if a system could be designed to advise a client as to the information required at various stages and under certain circumstances during a project. Such a system could well be extended to cover monitoring and control during the preconstruction period.

Comment.

Similar comments to the previous item.

4. Land/Building Economics

The development, valuation and use of land and buildings can be of prime importance on some sites. A system could be designed which would consider the various options allowing the developer to make decisions as to the type of building preferred and to calculate the subsequent return.

Comment.

Again, substantial research in the subject area would be necessary.

Marketing

In a recent article on marketing [16], Peter Rutland stated 'Every construction company in business today is performing marketing functions. The company that serves only the public sector has made a marketing decision by selecting that market. In the private sector, the marketing function will be different, probably more aggressive or dynamic, directed at the market-places', and then goes on to consider some of the ways a company can market and sell itself. Some of these keys to marketing and selling a construction company are:

- Company promotion
- Advertising
- Company brochures
- Business cards
- Newsletters
- Press Notices
- Exhibitions and Conventions
- Annual reports
- Public Relations
- Making a proposal
- Making a presentation
- Customer services
- Recording sales information

1. Determining Sources of Work

Work can be obtained from a wide variety of sources, contacts can be built up over many years and between many members of staff. An intelligent knowledge-based system could advise on possible sources of work and helpful contacts within organisations who may be able to assist with securing work.

Comment.

Probably a data-base would be the principal component of a computer system for this application. An expert system component may help the user in accessing the data.

2. Public Relations

Can be a specialised subject where experts are employed. An expert system could be developed to assist with PR decisions. Good public relations are important for every project and an IKBS could assist project management with such decisions and where they affect their particular project.

3. Advertising, Promotion and Publicity

All specialist functions of the marketing expert. An intelligent knowledge-based system could help management with decision making, where and how to proceed with various types of advertising, etc. Such a system could be linked to a conventional computer program which would analyse previous schemes and the results obtained from them.

4. Analysis of Market Information

Much general marketing information is available to be collected, collated and analysed. This analysis is important if market leads are to be followed up satisfactorily; at this time, most of the collection would be manual, the collation using some form of information retrieval system, and any analysis also manual. The analysis of this market information could well be helped by using some form of intelligent knowledge-based system.

5. Market Forecasting

Stefik [17], in a tutorial and subsequent articles and book, sets out expert system problems and includes as one of these, prediction. Prediction is an important feature when considering market forecasting, predicting the market movements and how any environmental, governmental or other changes may affect a market.

6. Product-Market Strategy

Having considered the market forecast, it is advisable to prepare a product-market strategy. This may, however, in the construction industry, be relatively simple and mean either/or both rehabilitation projects or new industrial units. It could be more sensible to spread the type of project undertaken over a range of project types and locations to avoid any sudden change in government policy away from one type of work and in favour of another. An intelligent knowledge-based system could help with the determination of a product-market strategy.

Estimating and Surveying

1. Bidding Strategy

When an estimate has been prepared, and prior to the submission of a tender, many aspects are considered before finally agreeing on a bid. A tender is frequently discussed by a management group at a tender adjudication meeting. Such a meeting is likely to be attended by the person preparing the estimate, together with directors and/or managers who will make the final decision about the tender submission. Any IKBS would have knowledge of management's thinking at this stage of tendering.

Research has been carried out at the Department of Construction Management at the University of Reading into the analysis of tender results. A knowledge-based system could well interface with this type of computer program which would then be able to compare results of previous tenders where similar contractors are included on the tender list.

2. Invitation to Tender

As soon as an invitation to tender is received, a decision should be made as to whether a tender should be submitted. This decision can be affected by many things, including present workload, anticipated resource requirements, type of project, location, client, professional consultants involved, etc. An expert system would be able to assess the information on the tender documents, together with the various clauses included in any contract documents. Having looked at all these aspects, it would then highlight the main items management would need to consider before accepting the invitation to tender.

Comment.

The system would have only one goal, i.e. to bid or not. While conceptually this is simple the knowledge base would be quite complex. A further problem is that the executives who provide the knowledge may have differing views. Rules based on consensus may therefore be difficult to establish.

3. Management of Estimate and Tender Preparation

Efficient estimate and tender preparation requires careful management. Much of the resource management can be effectively done using some form of conventional project management system. However, an intelligent interface to such a system could well prove to be helpful in the period between estimate to tender.

4. Cost Planning

Several aspects of cost planning could be helped by using intelligent knowledge bases.

- a) Historical price data is at present recorded, stored and is used as the basis for the preparation of subsequent approximate estimates. By improving the data storage methods to relate the analysis more accurately to the type of structure, location, construction period, etc., and by using an intelligent 'front end' to such a database, it would be possible to match more closely the type of structure being considered, and to forecast future likely increases in the construction costs, etc. Thus, the prediction aspects of the intelligent knowledge-base could be incorporated.
- b) A system could be developed which would assist with the preparation and analysis of a budget price indicating the various types of finishings available in a particular price range. Adjustments to the project could be considered in the light of any imposed limit or alteration to the budget.
- c) Price related control during the development of the design and production of information.

Comment.

Cost planning is the name given by quantity surveyors in Britain to the process of budgetary control during design. The procedures involved could be represented by an expert system that could provide junior cost planners with advice as to what their next action should be. This is a case in which the system would function differently according to the stage of the project.

5. Probabilistic Cost Estimating

Varying construction methods make a substantial difference to the overall cost of building any project. The optimum cost and profitability is what construction managers endeavour to find, however, although an operation may be completed at the cheapest sum, the method of carrying out the work may well affect subsequent operations, requiring them to be completed at a higher cost figure.

Therefore, an intelligent knowledge-based system could consider various aspects in a method statement, for all or part of the project, and consider the most economical combination of operations.

6. Forms of Contract

Each different form of contract offers differing rights and obligations to each of the parties associated with that contract. An intelligent knowledge-based system could assist them all by advising as to their varying positions under the contract, ie for the JCT form of contract:

- the rights and obligations of the Contractor
- the powers of the Architect
- provisions as to Sub-contractors
- certificates and payments
- determination of the contract
- arbitration provisions
- etc.

7. Contractual Claims

A system acting as a claims consultant could provide invaluable advice and information at an early stage for the contractor, quantity surveyor, architect and client. Such a system would be able to tell them of their claim vulnerability, and/or likely success of any claim.

8. Methods of Measurement

There are many differing methods of measuring and valuing building work. The standard method of measurement is now approaching its seventh version. An expert system could assist with evaluating the varying advantages and disadvantages of using the systems, and make some comparisons between them and assist the professionals with changing from one system to another.

A second intelligent knowledge-based system could advise the surveyors on the various sections and clauses of the standard method of measurement.

9. Cost Comparisons

The cost of a contract is of prime importance to the contractor. His profitability depends on efficient working and low costs. Problems can frequently be detected early by obtaining accurate contract costing figures promptly.

The development of an intelligent knowledge-based system to assist with the preparation of income and expenditure statements together with their comparison and reconciliation could well assist this management function and highlight the items requiring specific attention.

Further estimating and surveying subject areas worthy of consideration as intelligent knowledge-based systems are:

- A system to help analysis of the effect of organisational factors upon production costs
- Cash flow and forecasting based on the estimator

- The factors affecting the adjudication of costs by management
- Historical analysis of bidding performance
- Relationship between the original estimate, the tender documents and the value and cost of a project.

Project Planning, Management and Control

Project planning and control has already been seen as a suitable subject area for the development of expert developed, including some work at Loughborough University of Technology. Reference to some of the systems has been made in a previous section of this report.

1. Choice of Planning Method

A variety of planning techniques and methods of presentation are available to the planning engineer. All these techniques would not be suitable for any particular project and an intelligent knowledge-based system could well assist with the selection and use of relevant techniques. Such a system would consider the use of bar charts, logic diagrams, linked bar charts, plotted network, arrow and precedence diagrams, elemental trend analysis, etc.

Comment.

A demonstration system has been developed at Loughborough. A possible extension of this system would provide advice on the level of detail and of sophistication to be adopted, on sources of data and on methods of dissemination of the plans in a manner that would stimulate effective project control.

2. Preparation of Construction Programmes

Project planning systems are now available which allow the user to physically create the planning network on a graphics screen using computer aided design techniques. However, apparent complication of network analysis systems continues to cause some resistance towards the general acceptance and use of such systems. An intelligent knowledge-based front end to such a package could well aid their preparation by advising on aspects such as:

- Activity identification and description
- Determination of activity sequences
- Prediction of activity directions
- Determination and presentation of production methods

3. Representation of Network Analysis Knowledge

One form of representing knowledge in the knowledge bases of expert systems is to use semantic nets. The structure of the nets somewhat resembles that of a network used in critical path analysis. Further research is required to determine whether this similarity can be exploited to

enhance the knowledge base of a conventional network analysis system.

4. The Method Statement

Before planning a project, it is important to consider the overall method of construction and to prepare a method statement. An intelligent knowledge-based system could assist this process. Knowledge of previous contracts could be entered into a knowledge base, and by basing construction methods on various criteria, similarities with other projects could be determined and used in the consideration of the method statement of new projects.

5. Safety, Health and Welfare

An expert system to consider and advise on the implications of the Health and Safety at Work Act 1974 and other health, safety and welfare legislation. Such a system could set out the responsibilities of the employers, managers and employees; enforcement procedures, prosecution and administration orders; arbitration procedures; and information on how the acts affect the subcontractor. Consideration could also be given to the mandatory requirements, moral and economic aspects of safety.

Some other project planning and control domains worthy of closer consideration:

- The choice of on site or off site production of components
- Plant selection
- Site layout
- Temporary works
- Optimisation of time and costs: resource levelling
- Selection and appointment of project managers
- The choice of in-house or external project management
- Cost related planning for the production process
- Buildability
- Security

Comment.

As reported in section 3, we have prepared a system for selecting materials handling plant.

Training

The use of intelligent knowledge-based systems designed to include the use of interactive video disks is seen as a powerful tool to assist in training. This method of approach could well be used for the training of management, technicians and craftsmen at all levels of the construction industry.

It is particularly suited to the training of technical and craft subjects where the use of pictorial representation is of major importance, but could also be used for many areas of managerial training in subjects such as safety, etc., where the further development of management games could prove to be a very successful training medium.

One major obstacle at this time would be the cost of video disk technology. However, as techniques develop and costs are reduced, this could well be a worthwhile method of approach.

Clive Dym [18] suggests that such systems could assist 'computer aided instruction, or of self-paced learning, where the student is guided through a complex field by an expert system. In this model, educational software will be designed, using expert system technology, to guide a student through a set of exercises, say, help the student find and diagnose errors in his solutions, and then formulate better solution approaches. This kind of software can be used to expose the student to more complex and practical problems than can be done with standard textbook problems, and can be used to encourage reasoning and heuristic styles of problem solving.'

Resource Management

Procurement

The most important objective is to ensure that resources, labour, materials, subcontractor, plant and equipment, etc., are acquired in the most efficient way. This, however, may not be based solely on economy, efficiency and quality [19]. Intelligent knowledge-based systems for procurement would advise on the various implications associated with obtaining the right resource at the right time and price.

1. Technical/Managerial Staff

Senior management may well need to decide at an early stage whether suitable managerial and technical staff are available 'in house' or whether it will be necessary to employ external help, consultants, etc. Some form of IKBS could link into a database containing details of consultants known to or used by the company. Information to be considered would include such things as:

- Capacity and workload of own company
- Previous experience
- Possible suitable consultants
- Key staff
- Capacity and workload of consultant
- Proposed method of organisation and control
- etc.

Comment.

The selection of key staff to suit particular conditions within a project should be quite feasible. As one approach each staff member could be designated as a goal.

2. Contracts of employment

A system could be prepared to assist with the various

aspects of contracts of employment, both contracts of service and contracts for services. Such a system is likely to include the terms of any contract, express, implied and incorporated; variations of terms; written statements, etc.

It would also include the details of government employment acts and the effects of legislation on contracts of employment.

Financial Management

1. Capital Investment

Long term capital investment decisions, particularly where associated with advanced technology and computer aided methods. Consideration of investment using various investment decision tools:

Payback
Discounted cash flow
Net present value
Internal rate of return
etc.

Some tools are more suitable when considering long term investment in computer aided methods. [20]

2. Taxation

Company taxation, finance acts, and other laws and regulations relating to taxation methods on a company.

3. Financing Methods

Assistance in choosing the most suitable method of financing capital purchases: [21]

Purchase
Lease purchase
Hire purchase
Finance lease
Operating lease
Rental
etc.

Comment.

Here each method of finance can be designated as a goal.

4. Sources of Finance

Consideration of available sources of finance, internally or externally funded:

Government grants
Equity/Venture capital
Bank loans
etc.

whether short, medium or long term finance:

short-term - overdraft, short-term loan, bill finance, trade bill, acceptance credit facility, etc.

medium-term loan

long-term loan - term loan, sale and leaseback, etc. [22]

Comment.

Again each method would be designated as a goal.

5. Insurance

To assist with the decision on the type of insurance necessary for a company or project, and with claims under the insurance policy including:

Professional negligence

Employers liability

Public liability

Fire and theft of property

All risk policies

Contractual insurance - JCT clause 19(2)(a), etc.

Bonding

etc.

An intelligent knowledge-based system would also explain the relationships with the brokers, loss adjustors, surveyors, etc.

6. Loan Applications

A paper on 'The User's Perspective in Relation to Building and Construction Management' [23] referred to a number of categories for which expert systems are feasible. One of these categories is ensuring that nothing gets overlooked.

When preparing a suitable application for a loan it is important to include all the necessary and relevant information. A checklist in the form of an intelligent knowledge base would be one way of ensuring that those preparing the application details were aware of the information required. Such a system would include details of such things as:

Company details

history

products

resources

future plans

Reason for capital need, type of loan, short, medium or long term

Sum required

cashflow forecasts, etc.

Purpose for loan, details of plant and equipment, etc.

Method of repayment

Past balance sheets

Security

etc. [22]

Comment.

The use of an expert system to replace a check list is somewhat prosaic but may secure important benefits. For example, it can ensure that nothing gets overlooked and can direct the user only to the relevant factors. It should also be relatively simple to modify the knowledge base when experience indicates this to be necessary.

7. Arbitration

To advise on the advantages and disadvantages of arbitration, conciliation and litigation. Such a system would refer to the Arbitration Acts 1950/75/79 and other relevant legislation, the appointment and powers of an arbitrator, awards, costs, fees, and rights of appeal.

8. Interpretation of Accounts

A system to assist with the interpretation of profit and loss accounts, and balance sheets and how they may affect a company's profitability, rate of return, etc.

9. Company Doctor

An Alvey Directorate community club has been formed in the City of London to develop an expert system which will consider the 'health' of a company. Building companies, although similar to other companies in many respects, have their own additional problems specific to the construction industry. Since building companies have one of the highest 'mortality' rates, a system could be developed to advise and consider these additional building company problems.

Some other financial management domains worthy of closer consideration:

- Investment decisions - economics of property development; capital investment and rental income for development projects.
- Contract costing techniques, profitability and the comparison of costs, time and output.
- Budgeting - fixed and variable budgets; various levels of budgetary control.
- Cash flows and forecasting for companies and projects.

4.3 COMMENTS ON OTHER APPLICATIONS

The CICA/LUT report was directed towards applications that are clearly within the general subject of construction management. However there are numerous other potential applications in construction, for example in Quality Control, Maintenance and Design. Impressive work is in hand at CERL in

the subject of Quality Control and this topic will not be elaborated here. Comments on the other two topics now follow.

Maintenance of large items of construction plant is likely to be a very satisfactory domain. The expert system(s) would be designed to diagnose faults and recommend remedies. By this process the expertise of the plant manufacturer and that of the contractor's head office could be made available to the field staff even when they are in remote locations.

Design in construction covers a great variety of applications from scaffolding and temporary works to billion dollar permanent work. Some small demonstration design systems have been developed at Loughborough notably in regard to heating and air conditioning systems. These are based at present on pre-defined goals such as the various types of heating system. Conceptually these systems could be developed on an hierarchical basis such that, when one goal is found, the user is moved down to the next level of detail and the system would then seek goals at this level. The process could be continued to any desired level of detail. More sophisticated concepts for the use of expert systems in design are being developed at other centres and it seems very likely that these concepts will be needed in the longer term. The simple concept based on pre-defined goals (or design solutions) may suffice in the design of small scale temporary works.

4.4 ECONOMIC IMPLICATIONS

The potential applications mentioned above have deliberately been selected as simple relatively self-contained domains that could be developed, tested and implemented in the short term. We believe this to be appropriate because, in the construction industry, it is necessary to establish the credibility of a new concept before it has much hope of success. We believe however that, once some momentum is established in the use of expert systems it should be possible to combine systems to deal with more complex domains. Links could also be established with other computer systems such as data bases, planning algorithms, and discounted cash flow evaluation. We envisage for example that our application to select appropriate materials handling equipment will in due course be extended to deal with formwork strategy, time and resource scheduling, and the economic selection of equipment within the constraints of the company's financial policies.

The pay-off from expert systems must depend on the particular application. We have selected two for comment, namely plant maintenance and the bid/no bid decision.

Our experience to date suggests that an effective system for diagnosing the causes of failure in one particular type of plant (say very large excavators) could be developed for about £20,000 to £30,000 and that it need not be based on anything larger than an IBM XT computer. Thus the total cost, including hardware and implementation may be say £40,000. Such a sum is trivial in comparison with the cost of a large excavator and the savings, by avoiding ill-judged repair strategy, would probably pay for the system in one company in a year or two. If the plant manufacturer were to prepare the system and make it available to his customers the absolute pay off would obviously be enhanced by

one or two orders of magnitude. The distribution of benefit would be a matter for commercial judgement. Where the manufacturer takes the initiative the enhanced economic position would justify expert systems for smaller items of plant.

A system to advise a company as to whether it should bid or not against any new enquiry would almost certainly be unique to that company. However, if the bids involve a substantial design content the pay-off again could be considerable. The bid decision involves senior people in a company and usually several are involved on each occasion. If we assume 100 enquiries per year, 2 man weeks of decision time per enquiry, and an average salary with overheads of £40,000 per year the annual cost of the effort made by current ad hoc decision methods amounts to about £150,000 per year. Our present estimates suggest that a good expert system and supporting hardware would probably cost in the region of £30,000, so the pay-off could be very substantial.

By these two examples we are not suggesting that all the potential applications we have mentioned will have good pay off. Each application must be judged on its merits and some hard-nosed calculations will be needed to establish whether the system is worthwhile. We believe that realistic advance assessments of this kind will help in establishing the credibility of expert systems. As indicated above we consider this to be important in the construction industry.

5.0 CONCLUSIONS AND RECOMMENDATIONS

From this broadly based study our principal conclusion is that there is a very wide range of applications within construction in which expert systems can assist management. We share the view expressed by Frank Kearney that developments in the short term should concentrate on easily understood concepts.

In section 4 it will be noted that many of the potential applications require careful research in the domain before a satisfactory system could be produced. While we are enthusiastic about the long term value of expert systems in construction we believe that development effort should be concentrated initially on domains that could have substantial pay-off, for example

- o Diagnosis of faults in major items of construction plant and advice on appropriate remedies.
- o Advice at board level on whether to bid or not. This would be particularly appropriate for contractors whose bids are expensive to prepare, e.g. those offering design and construction.

No doubt there are many other applications with good pay-off. We single out these two, only by way of illustration.

Although we have looked at some larger shell systems we believe at present that applications should be developed for micro-computers. This should help to promote the acceptance of expert system technology and pave the way for sophisticated developments at a later stage.

Our development of the demonstration system (see section 3) has highlighted the difficulties in extracting realistic knowledge particularly where this is held in intuitive form. We believe that careful studies of the methodology of knowledge acquisition should be undertaken. We also believe that such studies should be undertaken on a team basis with contributions from both computer specialists and behavioural scientists.

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APPENDIX 1

KNOWLEDGE REPRESENTATION AND INFERENCE

1.0 INTRODUCTION

The purpose of this appendix is to introduce the terms used in the evaluation reports describing the knowledge representations and inferencing logics used by the shells.

The main tasks of expert systems are logical decision making and, depending on the domain, some mathematical calculation. Each system provides different levels of sophistication of logical and mathematical inferencing. Logical decision making depends greatly upon whether the problem is deterministic i.e. inhabits a black and white world where all conditions are certain and evaluate to either true or false, or uncertain i.e. where the belief in the evidence or credibility of the rules is uncertain.

2.0 CERTAIN KNOWLEDGE - DETERMINISTIC

The most basic level of logical inference is "propositional logic". This is a classical logic in which the absolute truth or falsity of a statement can be determined in a mechanical and predictable way. Each basic element is a proposition such as: "the road is a major road". These propositions can be joined using the connectives AND, OR, NOT to form larger propositions and rules such as:

IF "the road is a major road" AND "the road is on an embankment" AND "the height of the embankment is greater than 6m" THEN "a safety barrier must be provided".

Production rule systems represent knowledge as a set of rules in this IF ... THEN format. They use propositional logic to establish the truth of the "antecedent" statements, ie those before THEN. If the antecedent conditions evaluate to true, the rule sets the value of the "consequent" statement. If the rule fails, the consequent may yet be proved by another rule in the knowledge base.

The disadvantage of propositional logic is that it is impossible to reason about items within the propositions. This may lead to many similar questions such as:

"Is it true that "the height of the embankment is > 6 m.?"
"Is it true that "the height of the embankment is > 3 m.?"

because it treats every statement about the height of the embankment as a separate proposition

To overcome this problem, more sophisticated systems break down the propositions into smaller elements. Two levels of sophistication can be distinguished. At the first level, propositions including numeric terms and simple relations such as "greater than", "less than" etc. can be handled. At the second, a more general predicate logic able to match non-numeric terms is implemented.

In the first, a rule can include a numeric test such as:

"embankment height > 6".

The system will ask for and store a numeric value for "embankment height", and will automatically be able to determine the truth of the overall proposition. ESP/ADVISOR, and the deterministic sections of KES.PS, SAVOIR, and ENVISAGE employ this type of logic.

The fuller predicate logic systems allow propositions to contain variables representing non-numeric items, with more general relationships holding between them. The relations cannot be processed in the same automatic way that the numeric relations are. Instead the knowledge base author has to define when a relation and its arguments are going to yield a value of true. These non-numeric variables might be used in rules such as:

```
"X needs parapet if
  X built-on structure and
  X is-subject-to BE5-conditions"
```

where X is some object, which may be related to some other objects: "parapet", "structure", "BE5-conditions" by the relations "needs", "built-on", "is-subject-to". To find if there is a true instance of an X which needs a parapet, the system needs to find instances of facts in the database such as: "road built-on structure", "road is-subject-to BE5-conditions". APES and XI provide a predicate logic.

EX-TRAN 7 uses a very different representation to any of the systems mentioned above. It uses decision trees to represent the rules. The same deterministic rules can be represented as in ESP/ADVISER for example, but they look very different, even less like English, e.g.

```
[road_tp] :
  major : [v_height] :
    < 6 : nobarrier
    >= 6 : barrier
  minor : nobarrier
```

The system chains forward through the decision tree following the appropriate path out of each decision node. This tree could be interpreted in an English style similar to the rules used in the example above, i.e. "if road type is major and verge height is greater than or equal to 6 metres, then a barrier is needed".

3.0 UNCERTAIN KNOWLEDGE

The systems mentioned above all use classical logic, where all truth values evaluate to true or false. In some domains such a crisp view of truth and falsity is not practical and some measure of truth or uncertainty needs to be associated with statements. Such facilities will clearly be useful in predictive systems which might produce conclusions like:

"the earthworks will be completed by September"
 - probability 0.9

The uncertainty in the knowledge could be from a number of different sources.

i) The rules may be uncertain, i.e. the same antecedent conditions can be indicative of different conclusions e.g.

Damp patches on the walls indicates either:
- rising damp or
- condensation

ii) The evidence may be uncertain, some measure of certainty may need to be expressed about some subjective assessment:

Has the engineer exercised reasonable care and diligence?

The systems evaluated in this study used three main methods of dealing with uncertainty:

- 1) fuzzy logic.
- 2) Shortliffe type certainty factors.
- 3) Bayes theorems.

3.1 FUZZY LOGIC

Fuzzy logic measures the truth of a statement as a number between 0 and 1, and may therefore sometimes very loosely be referred to as a probability. There are some fairly standardised methods for combining these truth measures for example:

Proposition A is true with value 0.7

Proposition B is true with value 0.5

If we have a rule such as: If A and B then C, the truth value of C is taken to be the minimum probability of all the antecedents, i.e. 0.5.

If the rule states: If A or B then C, the truth value of C is taken to be the maximum probability of all the antecedents, i.e. 0.7.

Most of the systems dealing with uncertainty provide these implementations of the fuzzy logic operators for combining their probabilistic statements. There is no theoretical justification for taking the maximum or minimum values in every case. It works in the classical logic case where the truth values are 0.0 and 1.0 and does not usually provoke any objections from users. These operators are provided in KES.PS, SAGE, ENVISAGE, and SAVOIR, which also has some alternative implementations.

3.2 SHORTLIFFE TYPE CERTAINTY FACTORS

Certainty factors described by Shortliffe were used in MYCIN. The only system in the study that provided this type of uncertain reasoning was KES.PS. This system allows the knowledge base author to attach a certainty factor in the range -1 to +1 to the rule, e.g.

if vertical rise = significant,
& quantities = small,
& space available = limited,
then lifting equipment = midget cranes <0.75>

This means that the rule leads to that conclusion with a certainty of 0.75. A certainty factor of less than 0.0 indicates against the conclusion with that certainty, e.g. <-0.25> would mean that midget cranes are unsuitable with certainty 0.25. In practice experts will tend to write rules which prove rather than

disprove things. However, there may be a number of rules in the knowledge base variously proving and disproving the conclusion. The final tally of the likelihood of a given hypothesis is found by simply adding the positive factor, called the measure of belief, to the negative factor, called the measure of disbelief. When two rules both prove or disprove a conclusion the uncertainties are combined using formulae of the following form:

$$mb' = s * (1 - mb) \quad (mb = \text{measure of belief}) \\ (s = \text{the rule's certainty factor})$$

These formulae make the measures of belief approach their legal bounds asymptotically, as corroborating evidence is added.

The user is allowed to qualify his answers with a certainty factor. This factor is then used to reduce the rule's certainty by simply multiplying the two factors together. For example, if the user responds to the question "is the space limited?", with a certainty of 0.5 the overall certainty factor of the rule becomes $0.5 * 0.75 = 0.375$. Where there are many antecedent conditions in a rule, the fuzzy operators described above are used to tally the user's belief in the evidence i.e. if the conditions are connected by AND's the minimum certainty factor is taken.

3.3 THE USE OF BAYES THEOREM IN INFERENCE NETWORKS

Inference nets are used by many shells including, from our evaluation set, SAVOIR and its predecessor Micro-Expert, KES.BAYES, ENVISAGE and TESS. They can be seen as an alternative to production rules, e.g.

IF A AND B THEN C
becomes
C DEPENDS ON A AND B.

There is however a fundamental difference in the processing of such statements. The production rule does not give a value to C if A or B fail. The inference network statement always leads to a value for C once A and B have been established. A "network" consists of many such statements and a set of questions about A, B, etc. The choice of logical operations permitted on A and B sometimes includes the simple operators AND, OR, NOT etc, but the real interest in inference nets lies in the use of Bayes' theorem for modifying the probabilities of uncertain hypotheses according to the existence of evidence. The Reverend Thomas Bayes (1702-1761) considered how worldly evidence could be used to prove the existence of God and his posthumous theorem has now become a basis of modern decision theory. In its application to inference nets the theorem is used to calculate a modified probability of the result C as the existence of items of evidence A and B is proved or disproved.

The typical use of Bayes theorem in an inference network can be summarized by the following example which follows the format of ENVISAGE.

C DEPENDS ON
A AFFIRM 5 DENIES .1
B AFFIRM 3 DENIES .2
PRIOR 0.1

In brief, Bayes theorem takes the PRIOR probability given for C and modifies it using the AFFIRM factor if A or B are true or the DENIES factor if A or B are false. Either factor may be greater or less than one. From our study we feel that there are some misunderstandings about the application of Bayes theorem to inference networks particularly in the estimation of suitable weighting factors. A varied nomenclature has been adopted to describe the factors. We like the terms AFFIRM and DENIES which convey well the sense of the weighting they give to the truth or falsity of the evidence.

APPENDIX 2

DIALOGUE RECORD

The following sheets record a dialogue session on the expert system to select construction plant. The background is described in section 3.

.....Welcome to CONPLANT...

The expert system for plant selection in
multi storey construction.

Can you tell me whether you are familiar with CONPLANT?
(Y.../..N or an option) y

You seem to have used CONPLANT before. Remember the help
facility can be invoked by pressing 'h' if you get stuck.

>> Do you require the use of the debugging facility
available? - useful to debug the model
You are advised to answer 'N' unless you are familiar with this
facility.

Only an answer YES to this question will invoke the facility
(Y.../..N or an option) n

page 1

We shall now start the consultation on plant selection

I am now trying to find the suitability of the ground to take the loading of equipment. The questions presented to you are intended to find out:

- the internal structure of the soil
- external factors affecting the soil...

(I am currently trying to find out the ground conditions in relation to itssoil properties

>> The ground condition of the site has to be investigated to find out if the ground can take the loading of heavy equipment.

If you are in an office and have not visited the site it may be difficult to answer this question. Try to get details of the soil investigation which might help you to answer this question.

Does the ground consist of:

- 1) - soil or
- 2) - thin soil bed overlaying rock bed

enter a number and remember that an answer '1' shall be taken as unknown

(1...2, 1 if not known or an option) 1

(I am currently trying to find out the ground conditions in relation to
itssoil properties

3) The soil bed can be of four types, and the characteristics of
each layer will effect the foundations required for plant. Can you tell
me the soil description of your site. A soil classification chart
is provided with this question.

Enter your choice :

- 1) gravel
- 2) sand
- 3) silt
- 4) clay

Do you want to see more [Y, N] ? Y
as TYPE PARTICLE SIZE AVAILABLE FIELD TESTS

gravel	20-60mm p.s	no field test for strength
gravel	2 -20mm p.s	easily excavated and a wooden peg can be easily driven
sand	0.06-2.0 p.s	requires a pick for excavation and hard to drive a wooden peg
silt	0.002-0.06 p.s	can be moulded in the fingers
clay	1.t 0.002 p.s	extrudes between fingers but hard clay is difficult to mould as

Extract from: Ground Engineering Equipment & Methods - F.C.Harris

(1..4, 1 if not known or an option) 2

(I am currently trying to find out the ground conditions in relation to itssoil properties

>> When a site is located in built up areas it is quite common to have open excavations protected and unprotected which may have been unforeseen during feasibility studies. It is important for me to check on this before advising on plant to be used. Can you tell me whether there are such open excavations outside the site boundary.

Answers:

- 5 if there are unprotected excavations
- 3 if there are partially protected excavations
- 0 if you are uncertain
- +3 if there are excavations but protected
- +5 if there are no excavations around site

(-5...+5 or an option) 3

>> Now I have completed the questions on ground conditions. Do you wish to see a sub-report or simply carry on with the consultation.

Please enter your choice:

- 1 - to see the report
- 2 - to carry on with the consultation

(1..2 or an option) 1

The Report is:-

The evaluation of the ground condition is now complete and my assessment is that.....

The ground should be able take the load of heavy plant.

**** Physical Parameters ****

I am currently trying to find the shape of the building so that I can later ask you the physical dimensions of the structure

>> Can you tell me whether your structure is circular, rectangular or square

Enter your choices

- a) - circular
- b) - rectangular
- c) - square
- d) - any other shape

(Enter 1 Characters or an option) b

I am currently trying to find the actual size of the building.....

>> Can you give me the width of the building in linear meters. You need not be very accurate in the reply to this question

(0...100 or an option) 65

I am currently trying to find the actual size of the building.....

>> Can you give me the length of the building in linear meters. You need not be very accurate in the reply to this question. If you selected an uncommon shape press 'A' for details to answer the question

(0...100 or an option) 85

>> The answers given by you for the dimensions of the building indicates that the building is too wide for normal construction procedures. It is common for the designers to have a core in the centre of the structure so that the reach needed can be reduced by erecting lifting equipment in this core. Does your building have a central core?

(Y...!..N or an option) y

>> In your reply to the previous question you told me that a core was present in the building. Is there a roof above the core?

(Y...!..N or an option) n

>> Most of the construction methods are largely dependent upon the

number of floors of a building. Can you indicate the number of floors in the building.

(1..50 or an option) 29

>> Can you indicate the average height of each floor in the building. Please answer in meters.

(0 To 10, ! if not known or an option) 3.5

** Access roads & obstructions **

I am currently trying to find the state of site access

>> Can you tell me whether there are sufficient access roads on site. Site access roads must be at least 4 to 5 meters wide so that heavy plant and trucks could travel. Please decide from the options given the most appropriate for your site.

Enter your choice :

- 1 - Access roads around the building
- 2 - Access roads only on two sides (lengthwise)
- 3 - Access roads on one side of the building only
- 4 - No access roads for heavy plant

(1..4, ? if not known or an option) 3

I am currently trying to find out whether there are any obstructions against use of plant.....

>> In built up areas one main obstruction to the use of tower cranes are nearby buildings. Sometimes these buildings will not be as high as the tower crane booms, but you may not be allowed to oversail. Do you anticipate problems of obstruction or precluded oversailing.

(Y...!..N or an option) y

>> Client imposed restrictions can sometimes restrict the use of your plant. For example you may have to hand over part of the building early for occupation and this may become an obstruction to work. Do you anticipate such problems ?

(Y...!..N or an option) n

>> Another physical obstruction could be overhead power transmission cables. In most cities these cables are underground but you are advised

to check on this. Are there any such obstructions on your site ?
(Y...I...N or an option) =

The Report says-

At this stage of the consultation I am in a position to suggest types of plant which can be used on site.....

The plant suitable to use on site are

Forklift trucks & dump trucks;

Tower cranes

Hoists - to transport light materials and men

>> The report indicated that tower cranes should be used on site. Now I shall offer you a menu from which you can request for specific details of tower cranes.

- 1) - Type of tower cranes to be used
- 2) - Size of tower crane
- 3) - Type of tower crane base
- 4) - location of the tower crane
- 5) - Do not require any further information (exit)

Enter your choice

Notes You can come back to this menu after an option

(1..5 or an option) 1

You should use tower cranes with luffing jibs to avoid nearby buildings.

>> The report indicated that tower cranes should be used on site. Now I shall offer you a menu from which you can request for specific details of tower cranes.

- 1) - Type of tower cranes to be used
- 2) - Size of tower crane
- 3) - Type of tower crane base
- 4) - location of the tower crane

5) - Do not require any further information (exit)

Enter your choice
Notes: You can come back to this menu after an option

(1..3 or an option) 2

The minimum boom length required is 32

The minimum height of mast required is 98

Notes: A 10 m clearance has been allowed between boom & top of building

>> The report indicated that tower cranes should be used on site.
Now I shall offer you a menu from which you can request for specific details of tower cranes.

1) - Type of tower cranes to be used

2) - Size of tower crane

3) - Type of tower crane base

4) - location of the tower crane

5) - Do not require any further information (exit)

Enter your choice
Notes: You can come back to this menu after an option

(1..3 or an option) 3

Use tower cranes on tracks and you will need 2 tower cranes with minimum boom length of 32 meters.

>> The report indicated that tower cranes should be used on site.
Now I shall offer you a menu from which you can request for specific details of tower cranes.

1) - Type of tower cranes to be used

2) - Size of tower crane

3) - Type of tower crane base

4) - location of the tower crane

5) - Do not require any further information (exit)
Enter your choice
Notes You can come back to this menu after an option

(1..5 or an option) 5

>> You are offered the option of restarting the model or to exit the
model at this stage.
Please enter your choice
1 - to restart
2 - to exit

(1..2 or an option) 2

END

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